

# LINEAR System Performance Analysis

Jenifer Brinker Evans

Space Control Conference

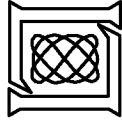
3-5 April 2001

## REPORT DOCUMENTATION PAGE

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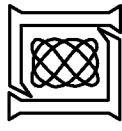
# Outline

- Background
- Performance Analysis -- The big picture
- Performance Analysis -- The details
- Future work

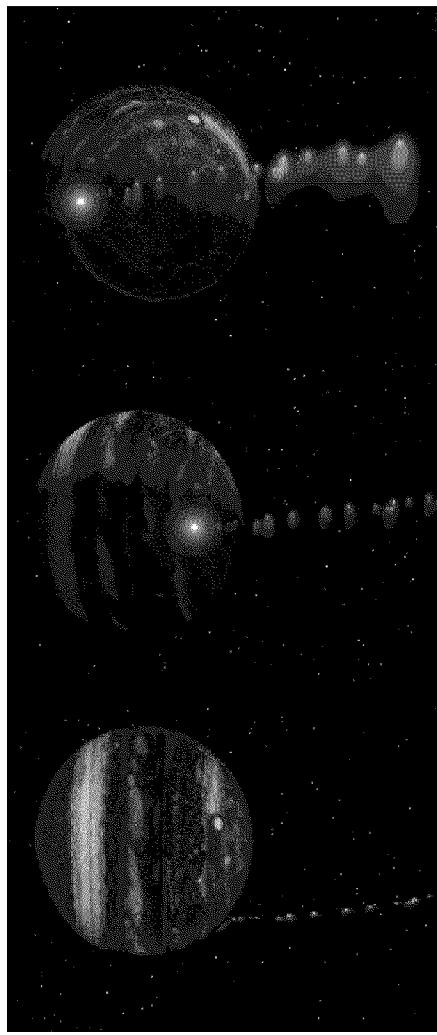
## Acknowledgements:

Lexington: Ron Sayer, Scott Stuart, Herb Viggh

New Mexico: Frank Shelley, Eric Pearce, Peter Trujillo, and the observers!



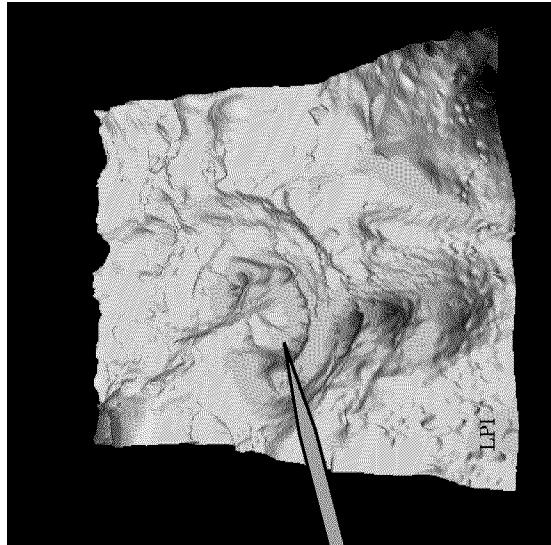
# Impacts Happen



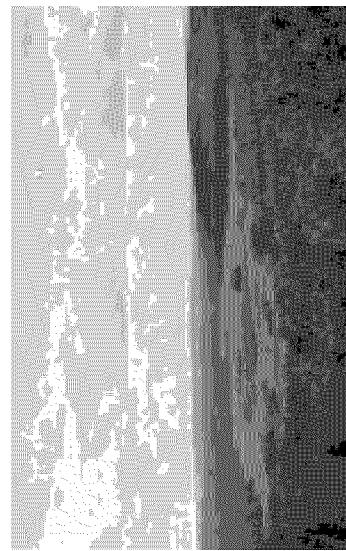
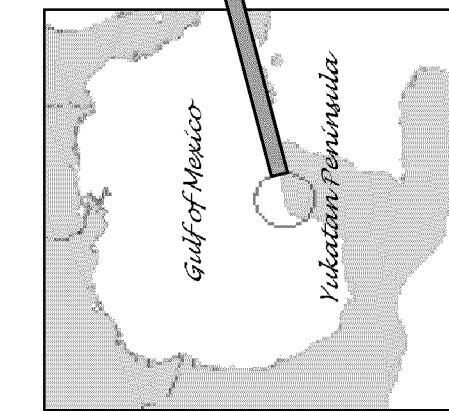
Shoemaker-Levy 9 and Jupiter (1994)



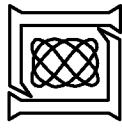
Meteor Crater, Arizona  
(~50,000 years ago)



Chicxulub, Mexico  
(responsible for K-T extinctions?)  
MIT Lincoln Laboratory



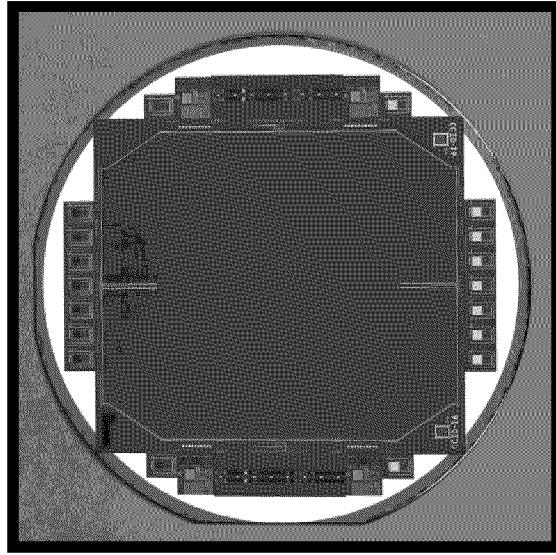
Tunguska, Siberia (1908)



# Lincoln Near Earth Asteroid Research (LINEAR)

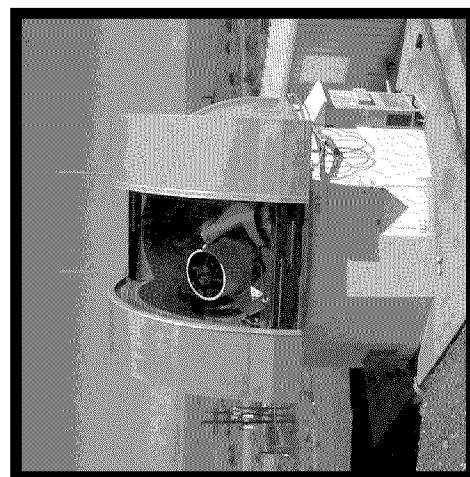


Experimental Test Site (ETS), Socorro, NM

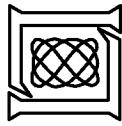


Lincoln Laboratory developed CCD

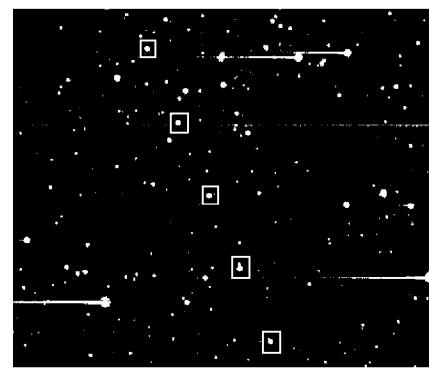
- 2560 x 1960 pixels, 2.25 arcsec per pixel
- Very low readout noise (few electrons per pixel)
- Back illuminated
- Peak quantum efficiency > 95%
- Solar weighted quantum efficiency = 65%
- Frame transfer to frame buffer in milliseconds



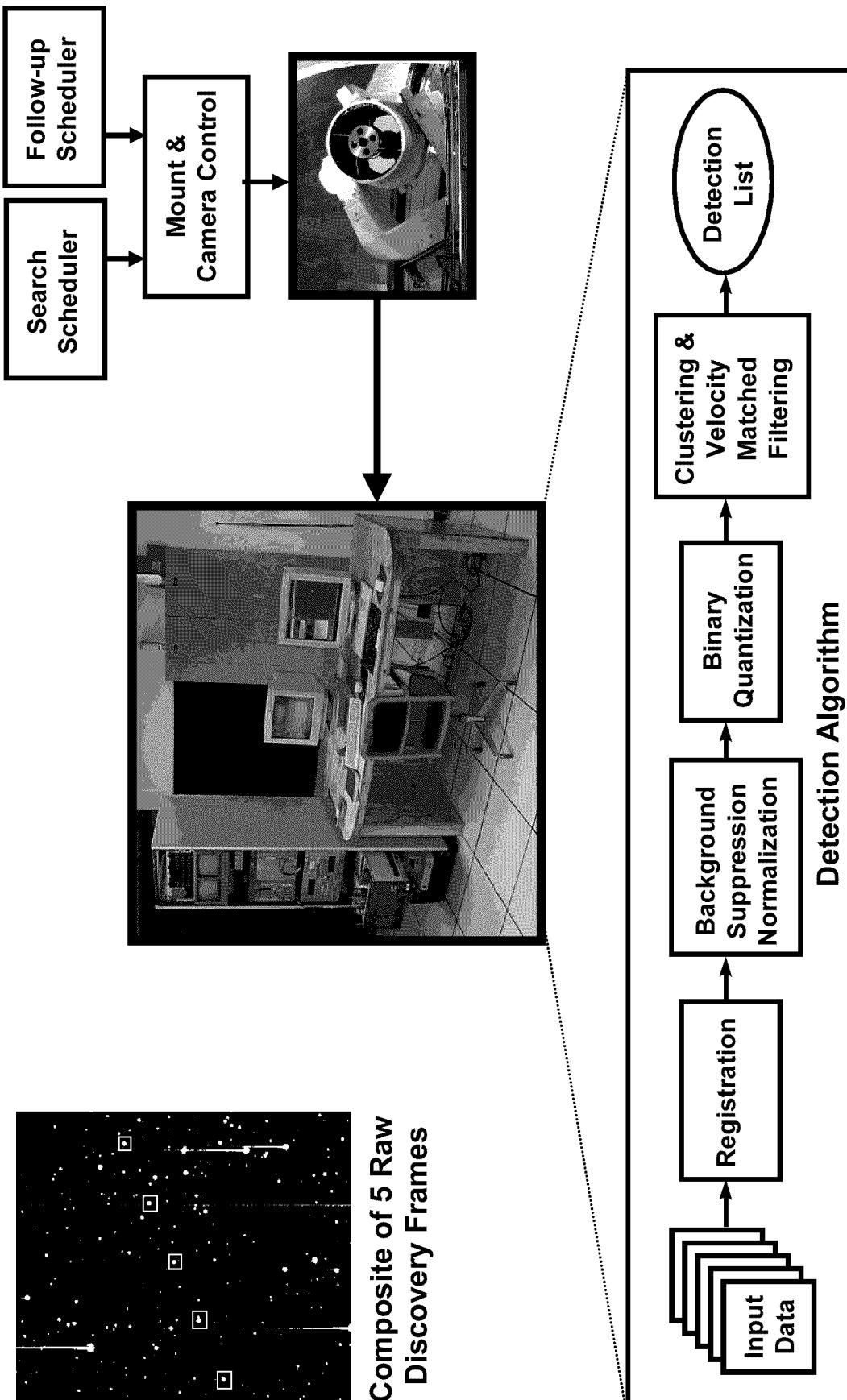
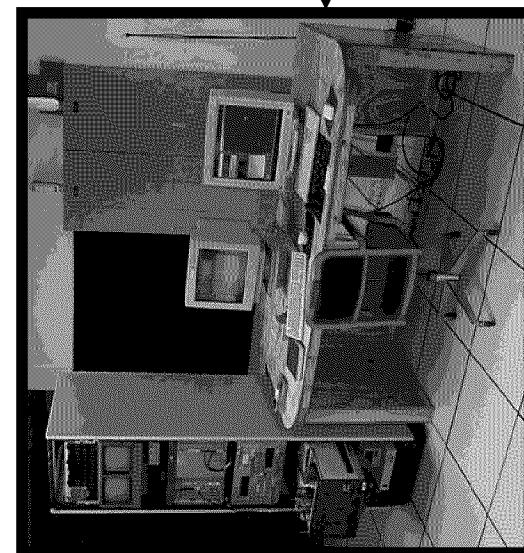
GTS-1 and GTS-2 (GEODSS) Telescopes

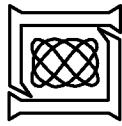


# LINEAR Detection System



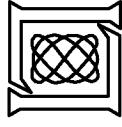
Composite of 5 Raw Discovery Frames





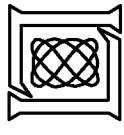
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- Performance Analysis -- The details
- Future work

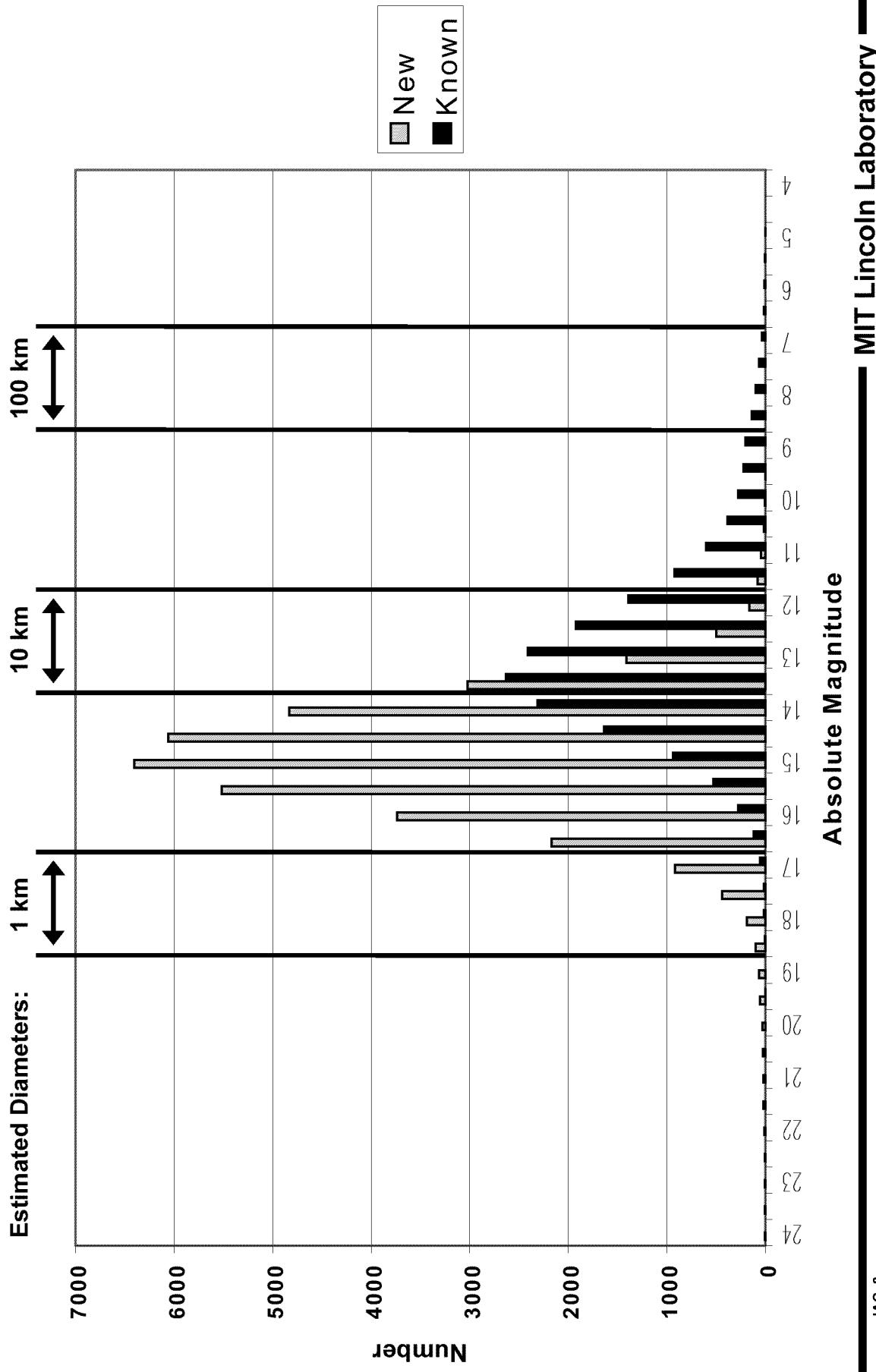


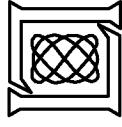
# LINEAR Observations and Discoveries

Lunar Dark Period	Obs sent to MPC	NEO Discoveries	Comet Discoveries	Total Discoveries
9/00	<b>211,014</b>	<b>39</b>	<b>5</b>	<b>9,667</b>
10/00	<b>340,743</b>	<b>22</b>	<b>1</b>	<b>3,827</b>
11/00	<b>229,071</b>	<b>36</b>	<b>1</b>	<b>1,433</b>
12/00	<b>234,978</b>	<b>14</b>	<b>0</b>	<b>Coming soon</b>
1/01	<b>231,377</b>	<b>23</b>	<b>3</b>	<b>Coming soon</b>
2/01	<b>227,916</b>	<b>19</b>	<b>2</b>	<b>Coming soon</b>
Totals 2001	<b>459,293</b>	<b>42</b>	<b>5</b>	<b>Coming soon</b>
Totals 2000	<b>2,268,676</b>	<b>258</b>	<b>17</b>	<b>44,953+</b>
Totals 1999	<b>1,301,999</b>	<b>161</b>	<b>22</b>	<b>28,922</b>
Totals 1998	<b>760,893</b>	<b>135</b>	<b>16</b>	<b>18,149</b>
Totals pre 1998	<b>83,762</b>	<b>19</b>	<b>0</b>	<b>2,123</b>
<b>Grand Totals</b>	<b>4,644,401</b>	<b>614</b>	<b>60</b>	<b>Coming soon</b>

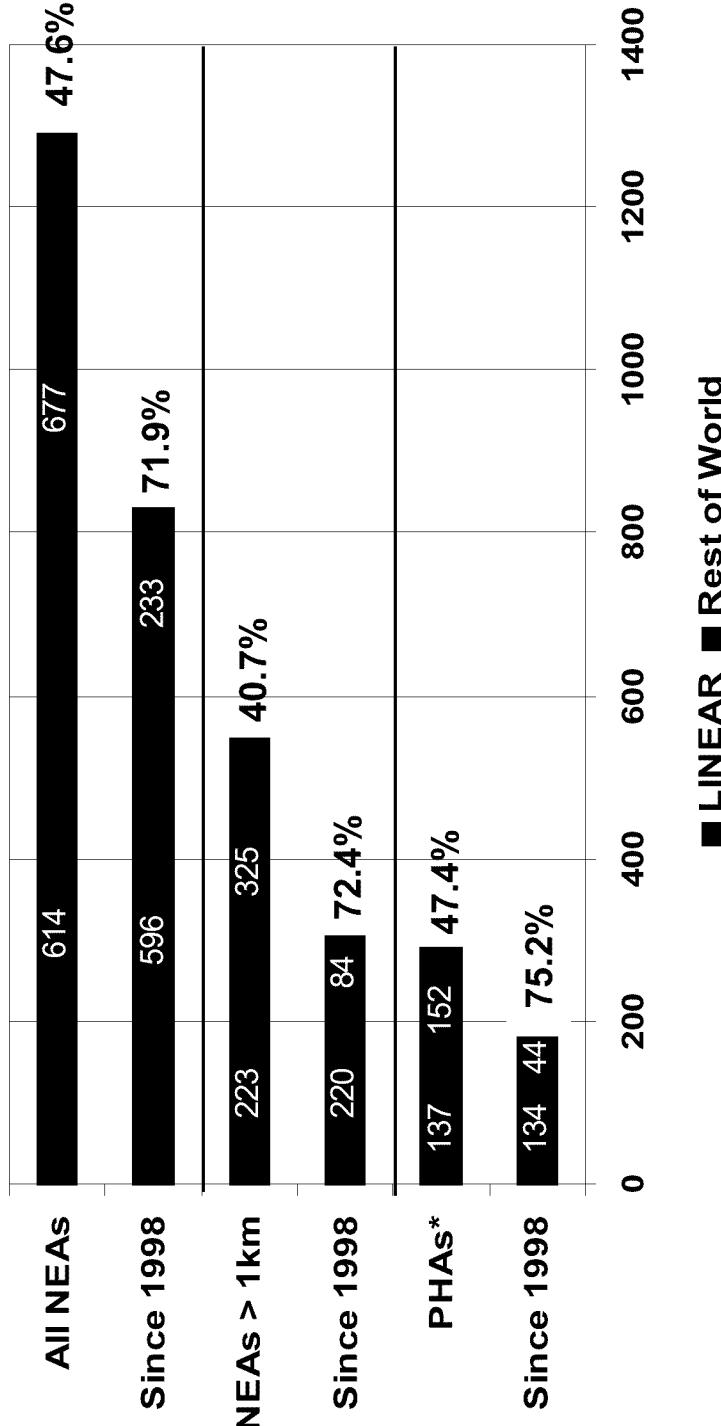


# Absolute Magnitudes of Asteroids Detected by LINEAR



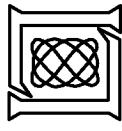


## LINEAR's Share of Near Earth Asteroid (NEA) Discoveries



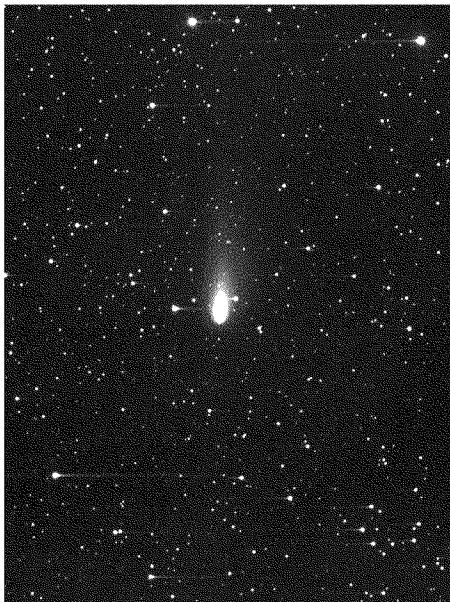
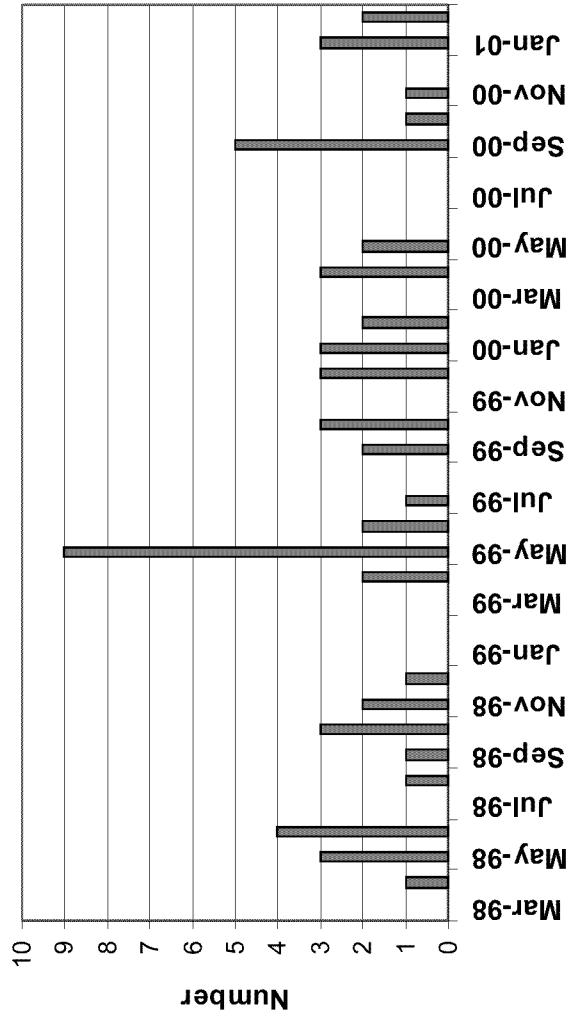
- First NEA discovered in 1898
- LINEAR has discovered 60 comets

\*PHA: Potentially Hazardous Asteroid, defined by Minor Planet Center.



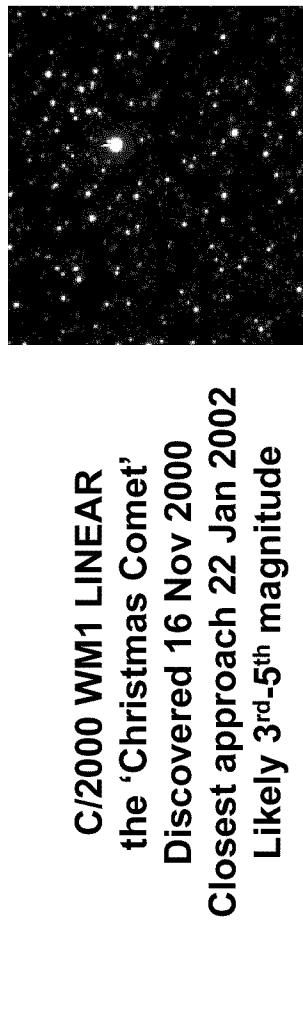
# LINEAR Comet Discoveries

## 60 Comet Discoveries



C/1999 S4 LINEAR

Discovered 27 Sept 1999  
This image from 25 June 2000  
Closest approach 23 July 2000 with  
peak magnitude ~6.5.  
Exploded and ‘vanished’ 26 July.



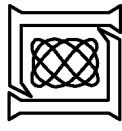
C/2000 WM1 LINEAR

the ‘Christmas Comet’

Discovered 16 Nov 2000

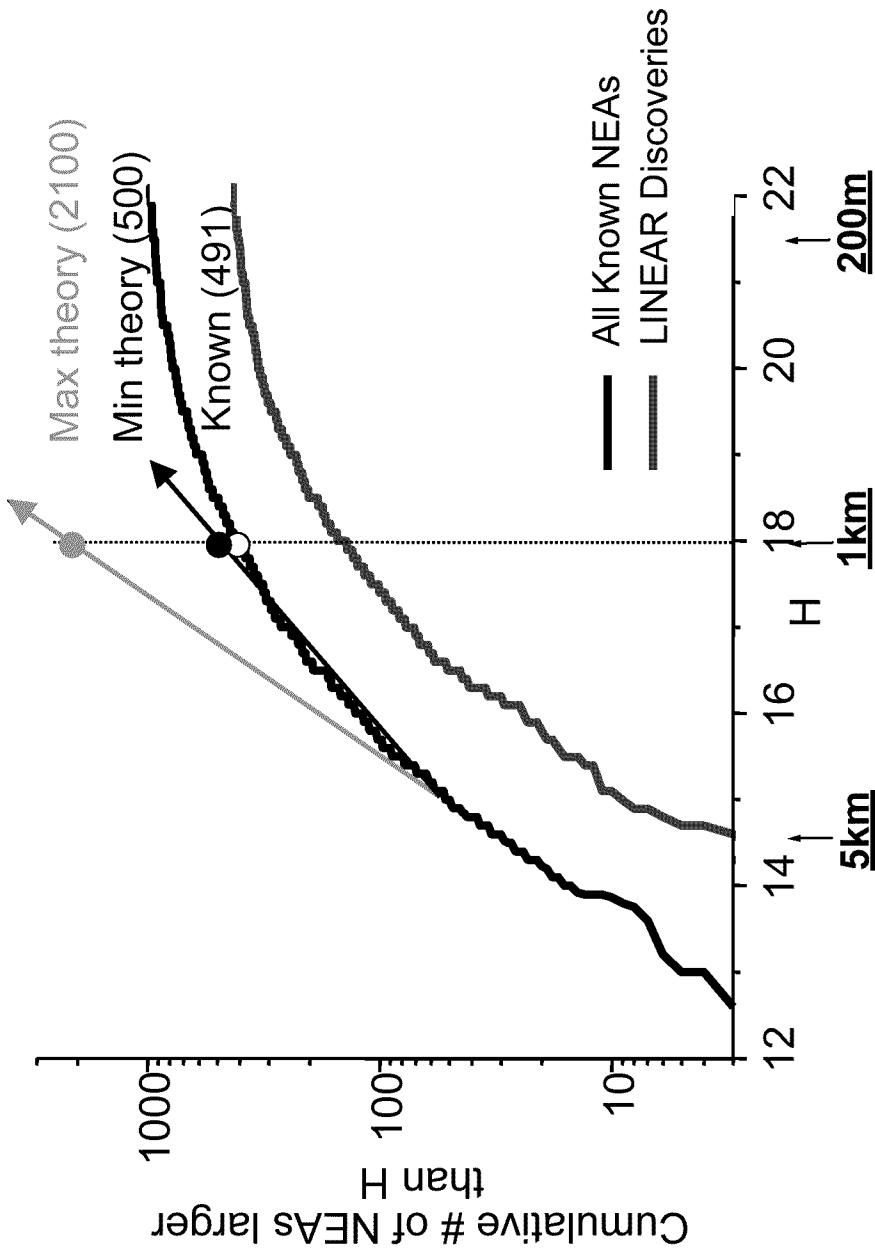
Closest approach 22 Jan 2002

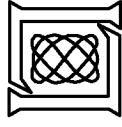
Likely 3<sup>rd</sup>-5<sup>th</sup> magnitude



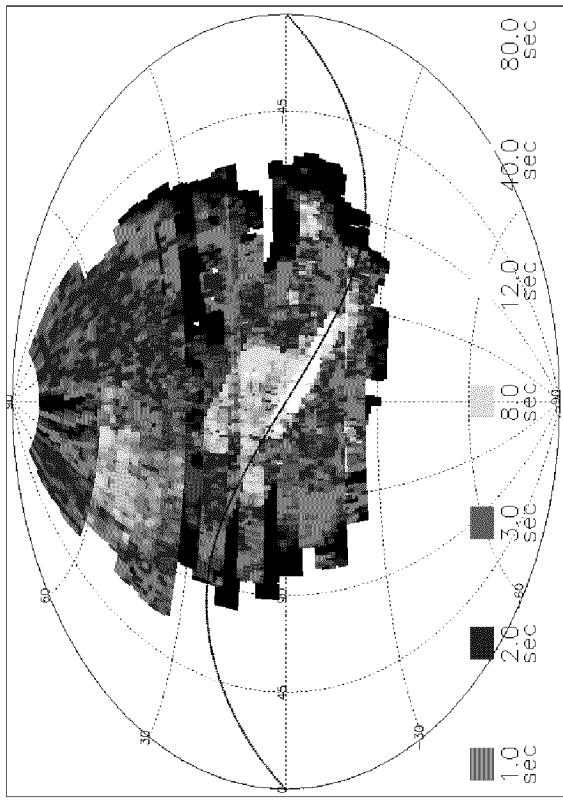
# NEA Population and NASA's Goal

NASA's Goal:  
Find 90% of NEAs greater than 1 km diameter by 2008

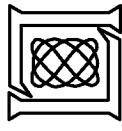




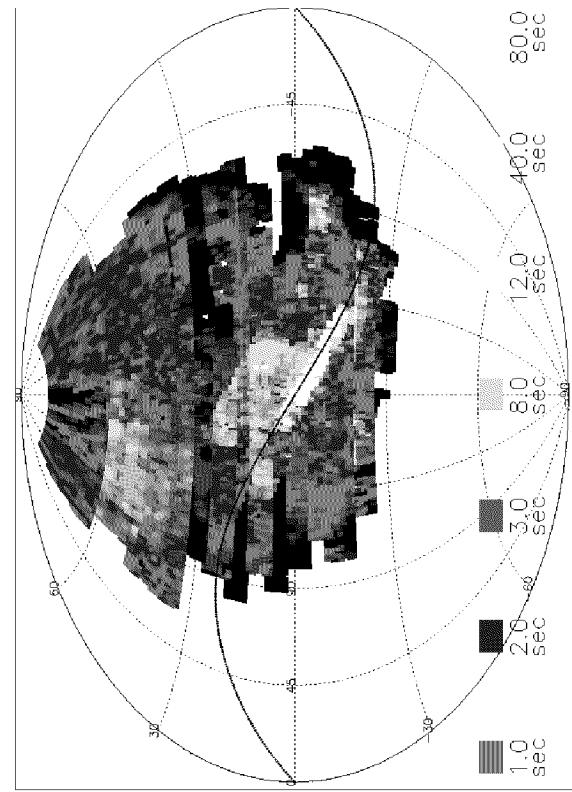
# LINEAR Sky Coverage



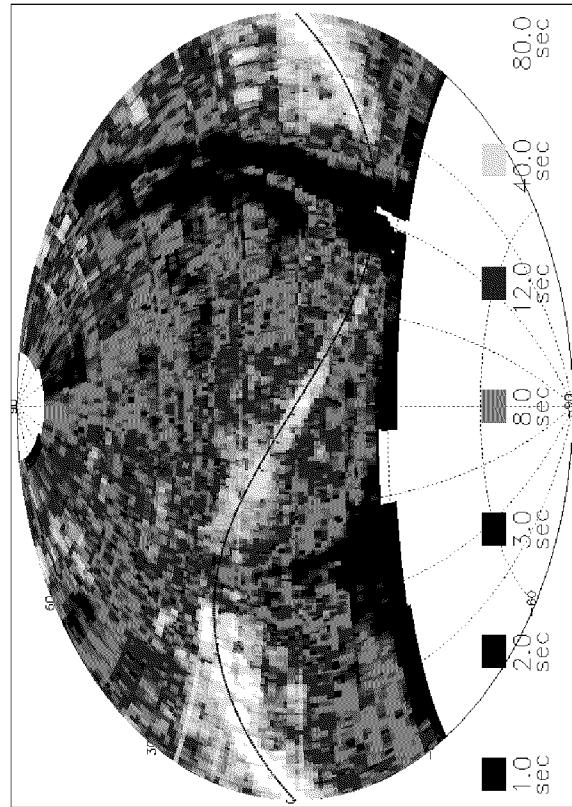
**April 2000  
2 telescopes  
Approximately 17,000 sq degrees**



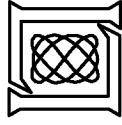
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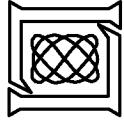


Sept 1999 – Sept 2000  
2 telescopes since February 2000

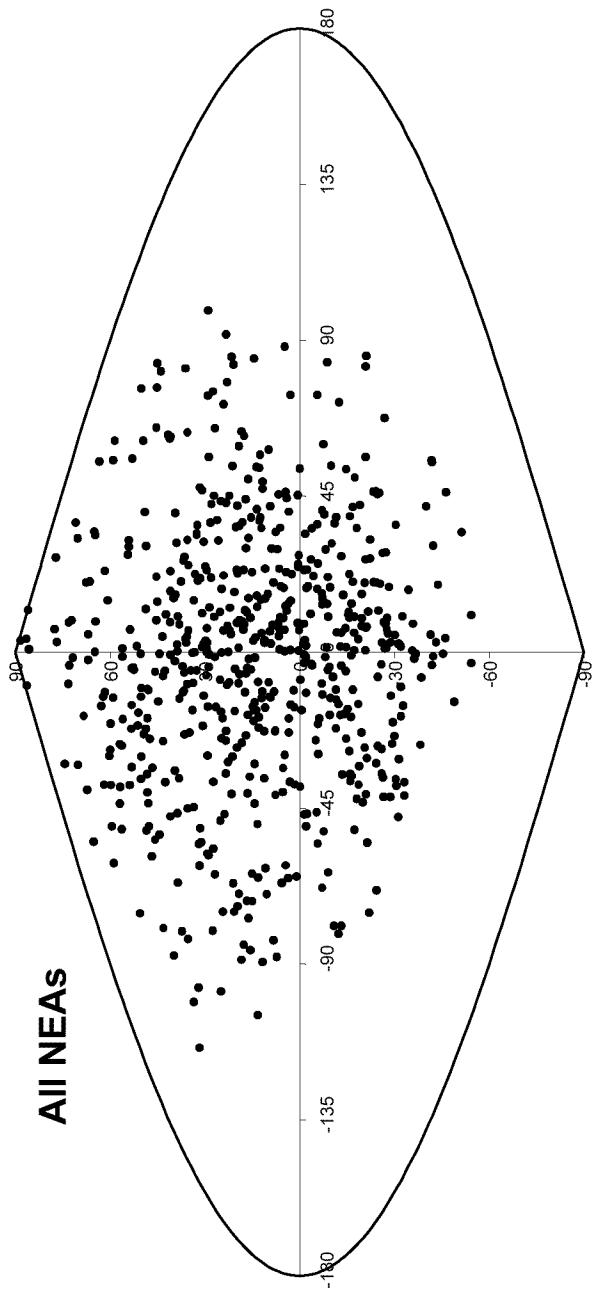


# Outline

- **Background**
- **Performance Analysis -- The big picture**
- **Performance Analysis -- The details**
  - **Search pattern effectiveness**
  - **Depth of search**
  - **Population estimate**
- **Future work**

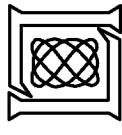


# Distribution of NEA Detections

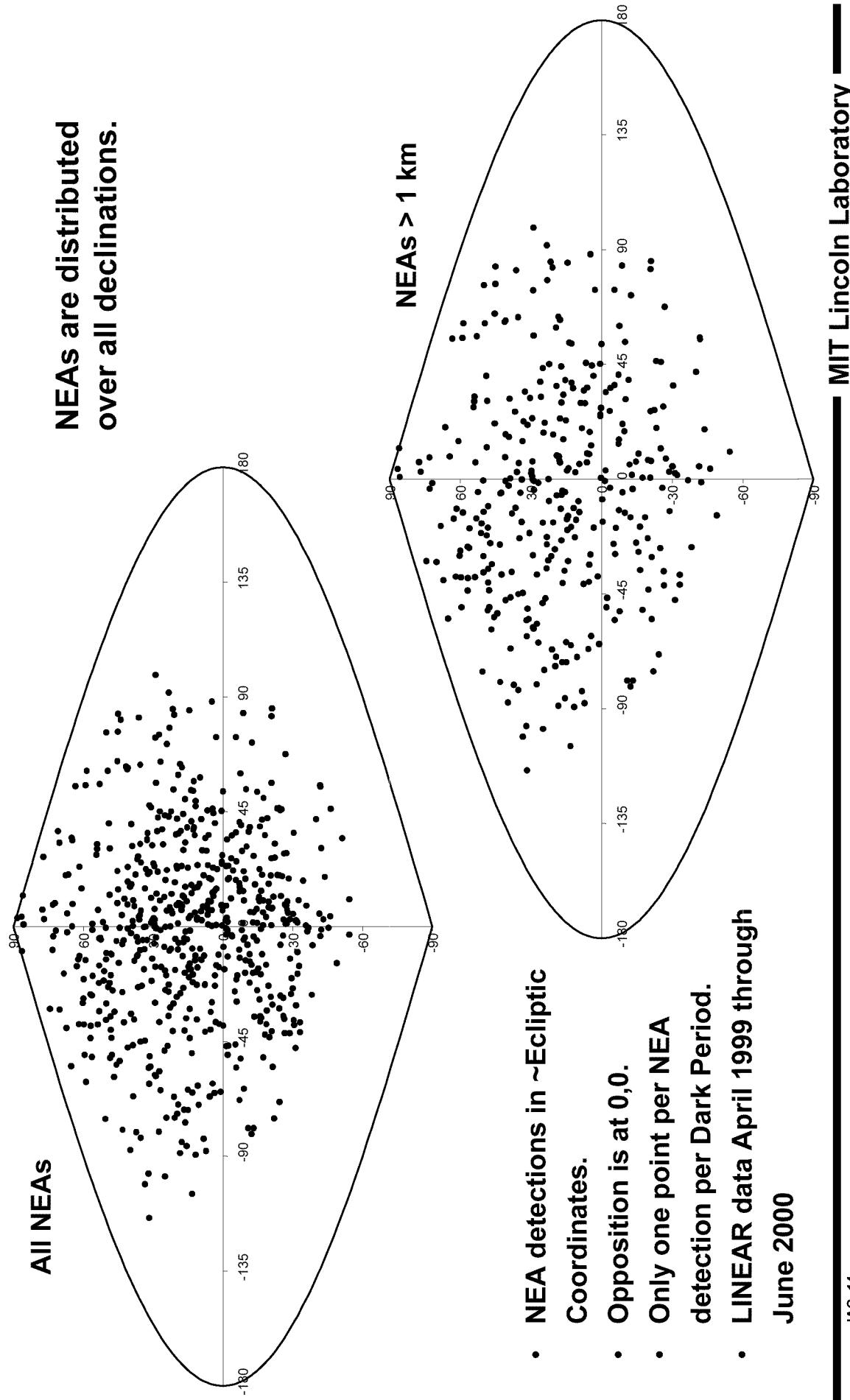


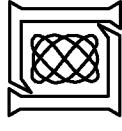
All NEAs

- NEA detections in ~Ecliptic Coordinates.
- Opposition is at 0,0.
- Only one point per NEA detection per Dark Period.
- LINEAR data April 1999 through June 2000



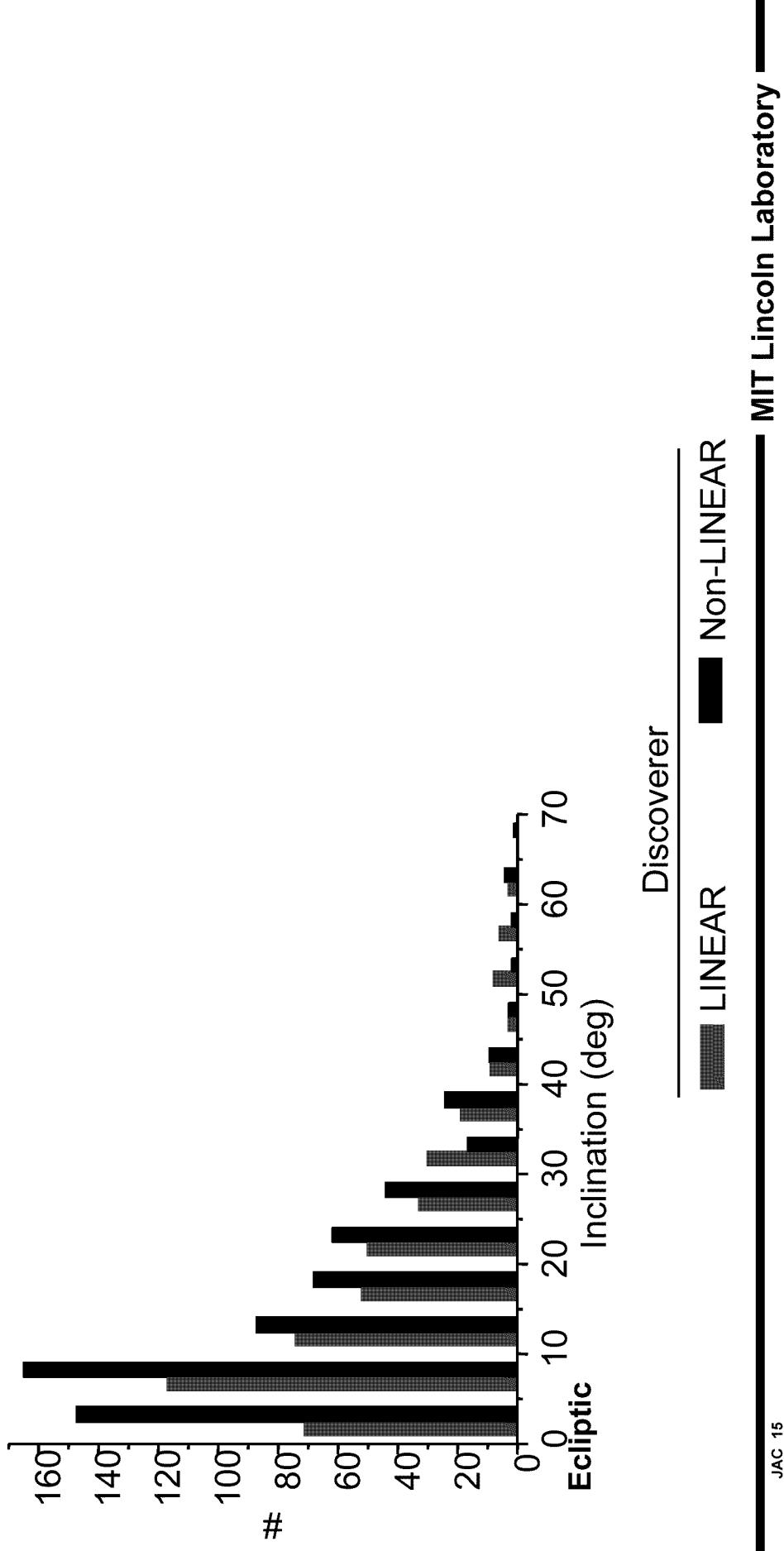
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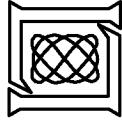




# Distribution by Inclination

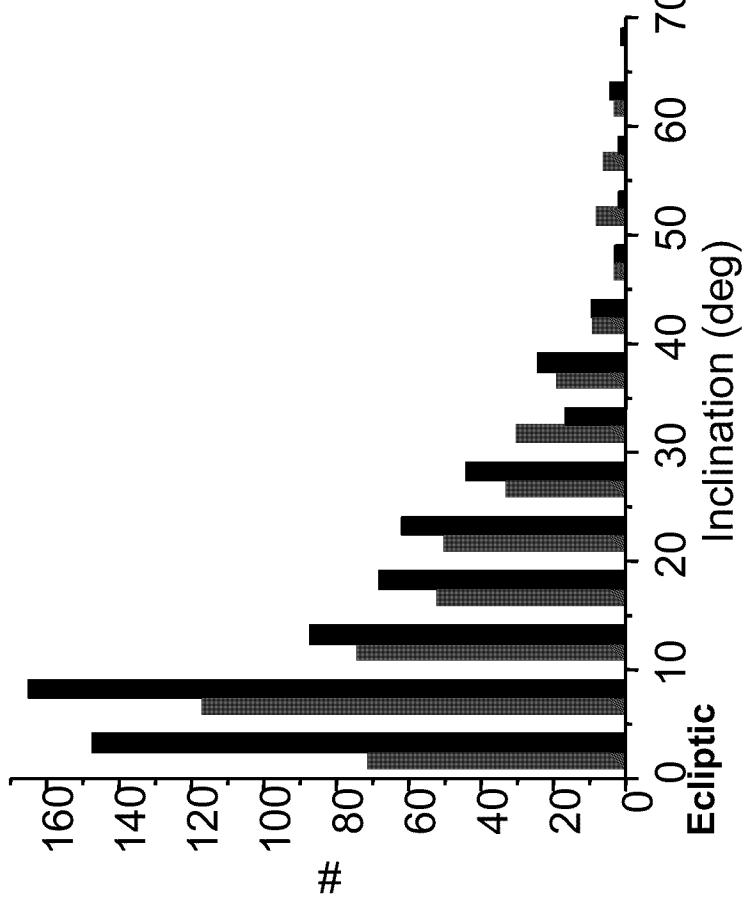
All known NEAs  
binned by inclination



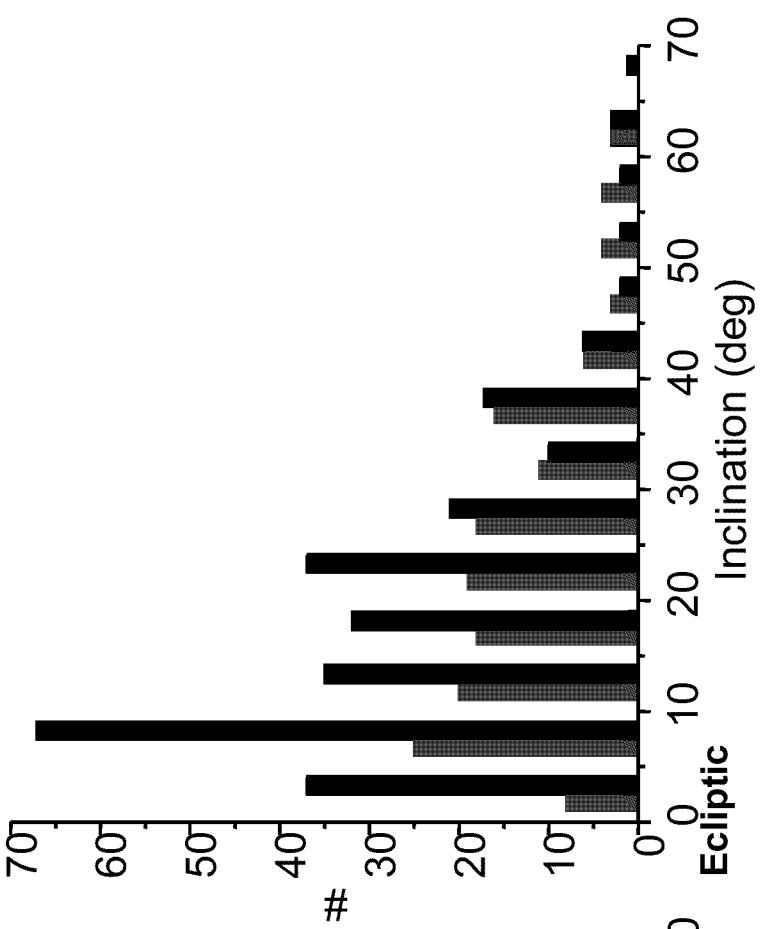


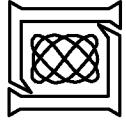
# Distribution by Inclination

All known NEAs  
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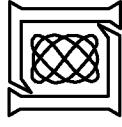


All known large NEAs  
binned by inclination



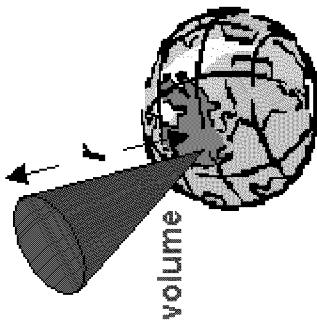


# Depth of Search



# Determining Search Volume

- Limiting magnitude can be translated to volume searched for an object of a known size/brightness. Solve for r.



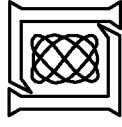
$$V_L - H = 5 \log(r\Delta - 2.5 \log[(1-G)\Phi_1 + G\Phi_2])$$

with

$$\Phi_1 = \exp[-3.33(\tan \frac{\beta}{2})^{0.63}], \quad \Phi_2 = \exp[-1.87(\tan \frac{\beta}{2})^{1.22}]$$

$$G = 0.15, \quad H = 18.0$$

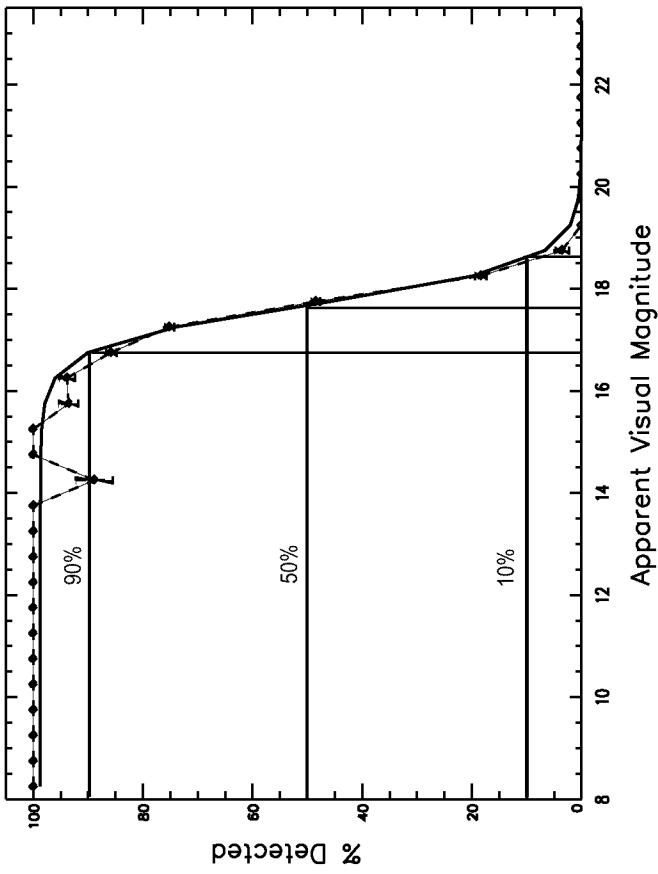
- Volume searched can be used as common metric for various search programs.
- Various search programs have begun discussing coordination to optimize overall search.
  - All programs need to characterize system capabilities.

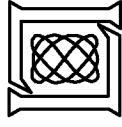


# Limiting Magnitude Determination

- Limiting visual magnitude affected by
  - Atmospheric conditions
  - Night sky brightness
  - Systematic losses
- Detection efficiency curve generation
  - Numbered and multi-opposition asteroids with known magnitudes.
  - Propagate asteroids to night of search
  - Compute percent detected in each bin
- Curve generated for each night

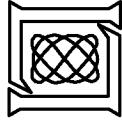
**Sample detection efficiency curve  
for a single night's search**





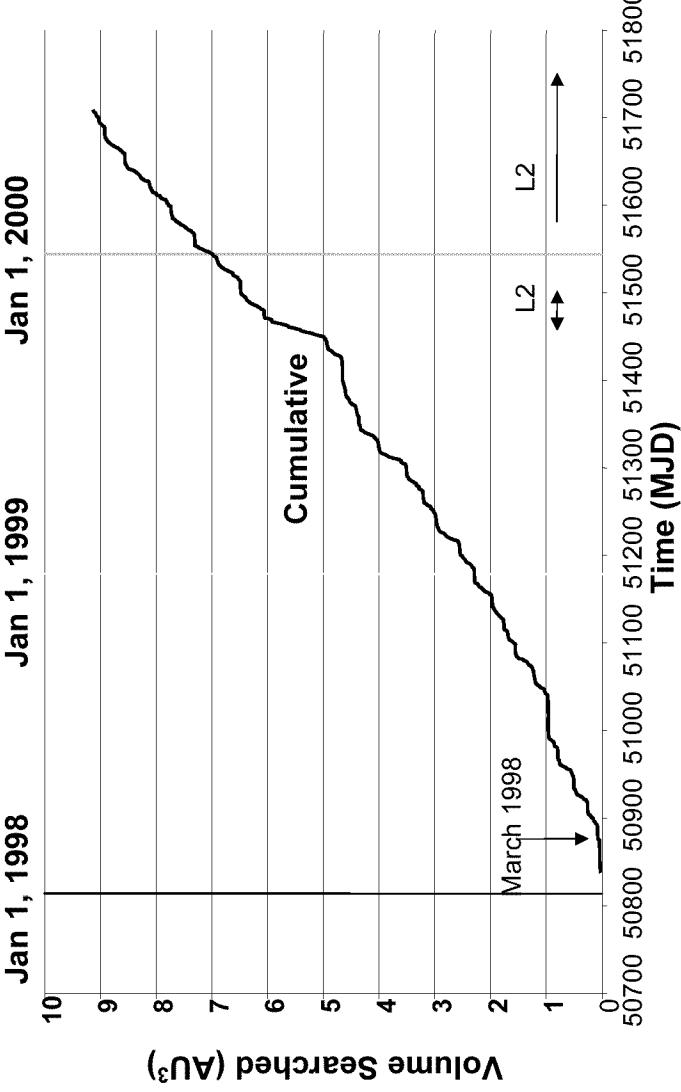
## Volume Searched by LINEAR

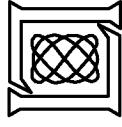
- LINEAR measures SNR6 value for every field searched.
  - SNR6 is known magnitude of a star with measured signal-to-noise equal to 6.
- SNR6 values agree with nightly based 50% cutoff detection efficiency value.
- Limiting magnitude values can be computed on a field by field basis.



# Volume Searched by LINEAR

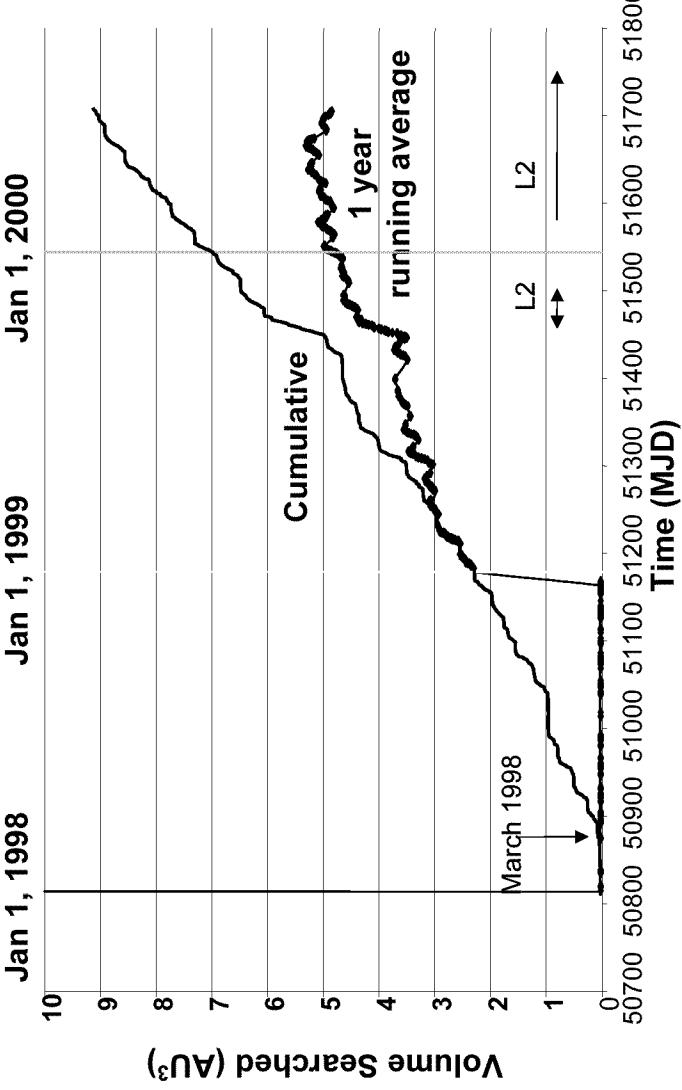
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  - Limiting magnitude values can be computed on a field by field basis.
- Calculate volume searched in  $\text{au}^3$

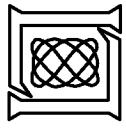




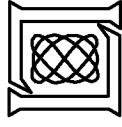
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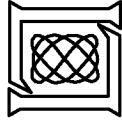


# Population Estimate



# Population Estimate for Large NEAs

- Topic of great interest
  - 2100 by Morrison, 1992
  - 750 by Rabinowicz, 2000
  - 900 by Bottke, 2000
- Typical method: 10's of detections and many Monte Carlo simulations
- New estimate by Scott Stuart, Lincoln Lab Scholar
  - Using 100's of detections by LINEAR
  - Using new inclination distribution
  - Using LINEAR detection efficiency information
  - Using Bayesian analysis



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1100 +/- 100

# Summary and Future Work

- LINEAR contributing 72% of NEA discoveries since 3/98
  - Approaching 50% of all NEA discoveries ever.
  - Searching 15,000 – 17,000 square degrees/month
  - LINEAR is contributing significantly to the NASA goal
- Continue system characterization to benefit coordination of various search programs and for self-improvement.
  - Generate detection efficiency curves for every night.
  - Analyze limiting magnitudes as a function of integration times and search patterns.
  - Experiment with and analyze various search patterns.
- Continue characterizing known NEO population.